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APPLICATION OF ERTS AND EREP IMAGES TO GEOLOGIC INVESTIGATIONS OF THE BASIN AND RANGE - COLORADO PLATEAU BOUNDARY IN NORTHWESTERN AND NORTH-CENTRAL ARIZONA

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Regional mapping using ERTS images has led to the recognition of two parallel northeast-trending systems of normal faults, the Bright Angel and Mesa Butte Fault systems, each of which can be traced at least 100 miles. Many eruptive centers appear to be localized along these fault systems or along their extensions. The faults are chiefly observed in Phanerozoic rocks and have minor displacement, but are interpreted by us to reflect fault zones of major displacement in the crystalline Precambrian basement. The location of epicenters of recent earthquakes and reports of earthquakes by residents in the region suggest that the Bright Angel and Mesa Butte fault systems are currently active.

Problems

No major problems have been encountered.

Accomplishemnts and Plans

Shivwitz Plateau

Fieldwork is essentially complete for the Shivwits Plateau area: about 2,000 square miles have been mapped at greater scales and better detail than required for the final compilation of 1:200,000. A few small areas remain to be mapped more thoroughly, and a few critical but small areas must be mapped in detail.

9p

In addition to providing a much more detailed geologic map than had been available until now, the fieldwork has yielded information on the following:

1) Type and distribution of structural features.
2) Paleogeography, especially the position of ancient scarps and valleys, and the relation of these to drainage.
3) Relation of groundwater to local geology, including factors locating usable concentrations of groundwater.
4) Success of the false-color IR ERTS photos in detecting and discriminating certain geologic map units.
5) Ways of using ERTS photos for filling in geology in areas between ground traverses.

To be done in the next several months:

1) Compilation and analysis of field data.
2) Compilation of photogeologic maps on ERTS bases.
3) Analysis of ERTS photomaps.
4) Comparison and correlation between ERTS and field data.
5) Preparation of papers and reports.

A paper has been prepared for the 4th Annual Conference on Remote Sensing of Arid Lands Resources and Environment, Tucson, Arizona, Nov. 12-16, 1973. The following abstract was submitted by Ivo Lucchitta.

PHYSIOGRAPHY AND STRUCTURE OF THE
SHIVWITS PLATEAU AREA, ARIZONA

Data acquired from ERTS-related studies of the Shivwits Plateau area, at the western boundary of the Colorado Plateau, are sufficient to make the following generalizations on the structure and physiography:

1. All faults are on the high-angle dip-slip type.
2. Most faults belong to sets trending north-northeast, northeast, north-northwest, and northwest.
3. The intensity of faulting increases to the east, toward the Hurricane fault, and to the west, toward the Grand Wash fault.
4. Away from the Hurricane and Grand Wash faults, faulting has produced graben and horsts. In the direction of the Grand Wash fault, faults and associated monoclinal flexures are consistently upthrown on the west side, possibly the result of pre-basin and range uplift of the terrain west and southwest of the plateau and not necessarily basin and range deformation.

5. The west-facing part of the upper Grand Wash Cliffs consists of hard-over-soft strata retreating from the scarp of the Grand Wash fault. The amount of cliff retreat appears to correlate with the amount of throw on the fault. This scarp is straight compared with the segment discussed below. Embayments result from drainages of Muddy Creek age in combination with protective lava caps.
6. The southwest-facing part of the upper Grand Wash Cliffs is an escarpment produced by erosion before movement on the Grand Wash fault and therefore older than the adjacent part of the Grand Canyon. The escarpment is deeply embayed and is the result of retreat of hard-over-soft strata from the uplift that existed southwest of the plateau before basin and range faulting. The adjacent part of the Grand Canyon probably was localized by a strike valley located at the foot of this escarpment before it had retreated to its present position.
7. The surface of the Shivwits Plateau slopes generally to the north. Development of the Colorado River in the area has modified a similar, older surface by removal of the relatively thin and soft Moenkopi Formation and by capture of older, north-trending drainages.
8. The lavas of the Shivwits Plateau, which are of late Cenozoic age, accumulated in a very broad and gentle valley of low relief trending and sloping toward the north-northwest. Similar flow directions occur in the lavas of the Uinkaret Plateau. The surface of the Shivwits Plateau probably was a cuesta trough formed at the base of the Shinarump Member of the Chinle Formation. The pre-lava topography is not appreciably dissected and thus may be a pre-Colorado River surface.

The Shivwits Plateau has sparse water resources. Most dependable supplies come from drilled wells, and the most productive of these is located where a postlava fault interrupts the nothwestward flow of ground water at the base of the lavas in the ancient valley. Exploration for additional ground water will be enhanced by improved understanding of the paleogeography and structural geology resulting from this study.

<u>Cataract Creek</u>

Field work was begun finally, after a record wet season. Mapping is being carried out in the northeast portion of the area near the Globe ranch.

Photogeologic interpretation of the ERTS frames of the area has resulted in delineation of two major fault systems mentioned in the Significant Results section. The analysis is the subject of a paper "The Bright Angel and Mesa

Butte Fault Systems of Northern Arizona" by E. M. Shoemaker, D. P. Elston, R. L. Squires, and M. J. Abrams to be given at the November Tucson meeting. The following comprises the abstract submitted:

Regional geologic mapping utilizing ERTS-1 multispectral scanning images has led to the recognition of two parallel northeast-trending systems of normal faults, each of which can be traced at least 100 miles. Many eruptive centers appear to be localized along these fault systems or along their extensions. The faults are chiefly observed in Phanerozoic rocks and have minor displacement, but are interpreted by us to reflect fault zones of major displacement in the crystalline Precambrian basement.

The Bright Angel fault system extends as a continuous zone of normal faults from Cataract Creek on the southwest to the Echo Cliffs on the northeast. Beyond the Echo Cliffs, the system continues northeastward, to the vicinity of Monument Valley, as a more diffuse, discontinuous zone of normal faults. The Navajo Mountain intrusive center lies along the discontinuous part of the system. Three major intrusive centers of the Mount Floyd volcanic field lie on the southwestern projection of the Bright Angel fault system. The Bright Angel fault and the Eminence fault are among the larger previously mapped individual members of the total system. If the eruptive centers are included as part of the recognizable structural system, the Bright Angel system has a total known length of 175 miles.

The Mesa Butte fault system, as now recognized, extends from the Tonto Rim on the southwest to Shadow Mountain on the northeast. Bill Williams Mountain, Sitgreaves Peak, and Kendrick Peak are principal calc-alkaline eruptive centers of the San Franciscan volcanic field that appear to be localized along the fault system. Red Mountain, Mesa Butte, and Shadow Mountain are prominent basaltic eruptive centers along the system, and the monchiquite diatremes at Tuba and Wildcat Peak lie on the northeast projection of the fault system. The total distance from the Tonto Rim to Wildcat Peak is about 115 miles.

Comparison of the Bright Angel and Mesa Butte fault systems with the residual aeromagnetic map of Arizona (Sauk and Sumner, 1970) reveals a close correspondence between the positions of the observed relatively minor normal faults and the margins of a series of large northeast-trending magnetic anomalies. Perhaps the most noteworthy feature of the aeromagnetic map is a 250-mile-long northeast-trending belt of large positive aeromagnetic anomalies that extends from the vicinity of Congress Junction to the northern border of Arizona. The Mesa Butte fault lies along the southeast margin of this anomaly belt. Another large positive anomaly, bounded on the southeast by the Bright Angel fault, corresponds to a sequence of metamorphosed basic volcanic rocks (Brahma Schist of Maxson 1961), where the crystalline Precambrian is exposed in the Grand Canyon. Precambrian displacement on the Bright Angel fault was described by Maxson (1961), where the Precambrian rocks are exposed. We believe that most of the large positive aeromagnetic anomalies along the Bright Angel and Mesa Butte fault systems probably correspond to bodies of basic metavolcanic rocks in the crystalline basement complex which have been offset along two major and perhaps several minor faults of Precambrian age. The normal faults that displace the overlying

Phanerozoic rocks have been formed by renewed movement along these ancient fault zones, in response to dilation of the crust from late Tertiary time to the present.

The ancient fault zones inferred to be present along the Bright Angel and Mesa Butte fault systems may be related in origin to the Shylock fault zone and Chaparral fault described by Anderson (1967) in central Arizona. Both the Shylock fault zone and the Chaparral fault have right-lateral transcurrent displacement. As shown by Anderson, the Shylock zone has a probable minimum horizontal displacement of 5 miles. A large contrast in the magnetic properties of the rocks on opposite sides of the fault zone, indicated by the aeromagnetic map, suggests the displacement may be several tens of miles or more. Comparably large right-lateral displacements may have occurred along the ancestral Bright Angel and Mesa Butte fault zones.

The location of epicenters of recent earthquakes and reports of earthquakes by residents in the region suggest that the Bright Angel and Mesa Butte fault systems are currently active. In 1912 an earthquake of intensity X(?) on the Rossi-Forel scale may have occurred on the Mesa Butte fault system.

References Cited

Anderson, C. A., 1967, Precambrian Wrench Fault in Central Arizona; in Geological Survey Research 1967; U. S. Geol. Survey Prof. Paper 575-C, p. C660-C665.

Maxson, J. S., 1961, Geologic Map of the Bright Angel Quadrangle, Grand Canyon National Park, Arizona: Grand Canyon Nat. History Assoc.

Sauk, W. A., and Sumner, J. S., 1970, Residual Aeromagnetic Map of Arizona: Univ. of Arizona.

Central Arizona

In support of fracture pattern studies as they may be related to groundwater reserves in the Coconino Plateau near Flagstaff, a high resolution (~ 1:5,000) stereoscopic model of the Woody Mountain well field was employed in the APC plotter in Flagstaff to produce a lineament map of the well field. The map, produced in collaboration with R. DeWitt, water resources geologist for the city of Flagstaff, is presently being evaluated by DeWitt in light of known and inferred structural trends. Some lineament trends appeared that do not conform to any known trends. DeWitt is in the process of selecting a site for a new well. This study is an extension of a study of lineaments in and near the Mogollon Rim carried out on ERTS photographs this spring.

Geologic investigations in the Hackberry Mountain area are nearly complete, as are compilations of geology at scales of 1:5,000 and 1:62,500. This study has shed new light on the problem of structural evolution near the Colorado Plateau margin in central Arizona. An abstract entitled "The Hackberry Mountain volcanic center, a Miocene-Pliocene dacite volcano in central Arizona"; by D. P. Elston and G. R. Scott has been approved for publication and submitted for presentation at the annual meeting of the Geological Society of America, Dallas, Texas, November 1973. The abstract reads as follows:

> The physiographic boundary of the Colorado Plateau in Central Arizona (Mogollon Rim) is interrupted at the southeast end of the Verde Valley by Hackberry Mountain and the Towel Peaks. These features are made up largely of flows, flow breccias, and tuffs of dacite and rhyolite composition. Their exposed thickness in this source area is nearly 1000 m.
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> Mapping has revealed that on the west side of the eruptive center, the dacites overlie basalt flows of the Hickey Formation. In the adjacent Black Hills, flows of the Hickey are reported as 14.6 to 10.1 m.y. old. Tuffs and flows of Hackberry Mountain are extensively inter-bedded with basaltic flows that issued principally from nearby vents along the Mogollon Rim. The post-Hickey basalt section locally is at least 425 m thick. To the north, apparently equivalent flows in and adjacent to the Verde Valley are reported as 8 to 4.5 m.y. old.
>
> Formation of the Hackberry Mountain volcanic center impeded and ultimately impounded drainage of the Verde Valley, leading to the deposition of lacustrine and evaporite deposits of the Verde Formation. This volcanic center was a principal source for the airfall and water-laid tuffs in the Verde Formation, and it very likely was a source for tuffs in other late Miocene and Pliocene deposits of the region, such as the Bidahochi Formation, some 180 km northeast.
>
> A paleomagnetic reversal chronology for more than 70 flows and inter-bedded sandstones near Hackberry Mountain, which contains 12 polarity intervals, has been provisionally correlated with the oceanic anomaly pattern. The correlation suggests that the initial, principal phase of dacite volcanism occurred 8.8 to 7.9 m.y. ago. This was followed by sporadic ash eruptions to perhaps 4.5 m.y. ago or less.

Another report describing the lineament systems of central Arizona entitled: "Structural Patterns and Landforms in Central Arizona", by D. P. Elston and G. R. Scott, has been prepared for the November Tucson meeting. Until this study, it was not realized that the Hackberry Mountain area was a major eruptive center from which only dacite and rhyolite were produced. The Hackberry Mountain volcanic center was responsible for damming of the Verde Valley, which resulted in formation of a lake and deposition of lacustrine beds and evaporites of the Verde Formation. The abstract reads as follows:

> Central Arizona contains a part of the southern margin of the Colorado Plateau and adjacent Mountain Region to the south. Salient physiographic features include: 1) the Tonto and Mogollon Rims, which mark the physiographic (but not structural) boundary of the Colorado Plateau; 2) the Verde

Valley, a northwest-trending trough that subsided mainly in the interval 10-5 m.y. ago (McKee and Anderson, 1971), in which lake beds and tuffs of the Verde Formation were deposited; 3) the Black Hills, which bound the Verde Valley on the southwest and include late Tertiary lavas once connected to equivalent flows on the plateau; and 5) the Hackberry Mountain volcanic center, which formed a dam across the southeast end of the Verde Valley during subsidence of the trough.

Gently dipping Paleozoic sedimentary strata crop out along parts of the Mogollon and Tonto Rims, and in parts of the Verde Valley and Black Hills. Precambrian metasedimentary, metavolcanic, and crystalline rocks occur in, and south and west of the Black Hills.

ERTS-1 multispectral images provide a synoptic view of the structural grain and physiography of the region. A regional photogeologic map has been compiled on an ERTS-1 photobase at 1:200,000 scale, using published and unpublished information. A complementary lineament map depicts both known faults and additional numerous lineaments that provide a general picture of the fracturing of the crust.

The lineament systems are most strongly developed in Precambrian rocks, somewhat less strongly developed in Paleozoic rocks, and least strongly developed (but certainly discernible) in the Tertiary volcanic rocks and valley-fill deposits. Several of the Precambrian facture systems can be traced into areas covered by Phanerozoic rocks, and some fracture systems clearly have served to control much of the present topography of the region. Major eruptive centers of the San Francisco volcanic field are aligned on NE- and N-trending (Precambrian) lineament systems (for example, Mesa Butte and Oak Creek). These fracture systems have strongly developed counterparts in Precambrian rocks that bound the west and south sides of the Black Hills (Shylock and Pine Mountain fault zones, respectively). The southeast end of the Verde Valley, and the Hackberry Mountain volcanic center, are at the intersection of NE-, NW-, and N-trending fault and lineament systems. Of these, the northwest-trending Verde fault system has served to define the western margin of the Verde Valley and the eastern margin of the Black Hills. This fault system, which commonly is considered to be the major controlling fracture system of the region, is much less conspicuous in the ERTS-images than the NE- and N-trending systems. We suggest that this reflects a younger age of the Verde fault, a fault marked by simple vertical displacement of basement rocks and not by transcurrent offsets such as those inferred to have occurred along the northeast- and north-trending Bright Angel, Mesa Butte, and Shylock fault zones (Shoemaker and others, this symposium). The ERTS pictures allow the geologist, for the first time, to observe fractures in rocks of different ages. Such studies will lead to a better understanding of the structural evolution of the crust.

Reference Cited

McKee, E. H., and Anderson, C. A., 1971, "Age and Chemistry of Tertiary Volcanic Rocks in North-central Arizona and their Relationship to the Colorado Plateaus", Geol. Soc. America Bull., v. 82, p. 2767-2782.

Field Spectrometry

An intensive effort was carried out to make ground spectra at or near the time of an ERTS overflight using the Portable Field Reflectance Spectrometer (PFRS). We had success during two passes, one in the Verde Valley and one on Red Lake, a playa south of eastern Lake Mead. Over 100 spectra were taken at 6 Verde Valley and 4 Red Lake sites. The spectra are currently being reduced and they will be used to radiometrically calibrate the images when they are received.

Measurements were also made as small cumulus clouds passed overhead in order to obtain light levels for comparison with cloud shadows in ERTS photographs. The light levels appear low enough (less than one-tenth of the full-sun value) so that it may be possible to use shadowed areas to obtain values for the atmospheric scattering component. More detailed analysis of this problem is now underway.

An abstract entitled "Use of ERTS Radiometric Information in Geologic Applications" by A. F. H. Goetz and F. C. Billingsley, has been submitted for the November Tucson meeting. The abstract reads as follows:

> Quantitative information can be derived from ERTS images after proper manipulation of the bulk digital images. Corrections must be made for atmospheric effects, both absorption and scattering. Ground spectra, taken *in situ* with portable equipment in the Verde Valley, are compared with images. The extent to which rock types can be distinguished using ERTS images is discussed.

Image Processing

Several types of classification methods are now being compared. The LARSYS programs are now running under VICAR, the JPL image processing system for the 360/44.

Color combined sets of three two-band ratios appear in some cases to provide the maximum possible discrimination and require considerably less computer time than LARSYS type of classification. A two-band ratio of a one-third ERTS frame now requires only 1.5 minutes to complete. The key to quantitative work with ratio pictures is the removal of the additive atmospheric scattering component. Our work with cloud shadows and ground spectra is continuing.

An effort is being made to use photometric function information as a discriminator. Two frames, 1032-17323 and 1015-17431, have been registered in the side-lap area. Ratioing of the registered segments has produced striking variations which are generally uncorrelated with rock type. The most likely cause is a change in albedo due to moist soil. The areas of maximum change are barely visible on the 1032-17323 frame and would not have been noticed otherwise. Further registration and ratioing for time variant phenomena and differences in photometric function are in progress.

Change in Emphasis

In our progress report for the period of 15 December 1972 - 15 February 1973, dated March 26, 1973, a statement was made that because of the newly discovered possible use of ERTS in the search for groundwater resources in central Arizona, some of the effort would have to be redirected to capitalize on the new application. Since then it has been possible to carry on both efforts and the Hackberry work has been continued. Our work with the USGS Water Resources Division in the Sedona area will be funded under a different task and therefore will not affect the proposed efforts as stated in the contractural statement of work.

Data Request Forms

One request for tapes from 2 frames was sent April 19, 1973.